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Evaluation of intrinsic vulnerability against seawater intrusion using the GALDIT approach. Application to the R'mel aquifer (North West of Morocco)

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Abstract

The map of groundwater vulnerability against pollution is a fundamental document for territory planning. This document allows decision makers to better manage and analyze the information needed to identify areas below which groundwater is vulnerable to pollution. In this context, and considering the strategic role of the R'mel aquifer in agricultural development and drinking water supply of Larache region, a groundwater vulnerability map to seawater intrusion using the GALDIT approach was applied. It is a parametric approach based on the combination of six layers of information relating to: **G**roundwater occurrence, **A**quifer hydraulic conductivity, Depth to groundwater **L**evel above the sea, **D**istance from the shore, **I**mpact of existing status of sea water intrusion in the area and **T**hickness of the aquifer. The Computed GALDIT index shows two classes of vulnerability fluctuating between the "Low" and "Moderate".

1. Introduction

The vulnerability of groundwater to seawater intrusion is defined in [1-2] as a "sensitivity of groundwater quality to an imposed groundwater pumpage or sea level rise or both in the coastal belt, which is determined by the intrinsic characteristics of the aquifer".

In this paper, the vulnerability of R'mel aquifer to seawater intrusion is evaluated using the GALDIT approach, integrating six parameters considered as the most important factors controlling seawater intrusion and using the Geographic Information System (GIS).

The application of this approach to the R'mel aquifer has been imposed due to the continuous and increasing stress of this aquifer until it is overexploited in some places.

The R'mel groundwater flows below a plain of the same name. This plain covers an area of 245 km^2 and extends over a 20 km, in south of Larache (Figure 1). Its natural limits are constituted by : The Miopliocen marl outcrops in North and South, Quaternary talus and rivers Smid El Ma and El Kihel in the East and North - East, Clay cement rubble of Oulad Ogbane aquifer in South East and the Atlantic Ocean in West. The local population is active in agriculture and food industry. Agricultural operations are mainly managed by the Agricultural Development Company (SODEA), Agricultural Company of Loukkos (CAL) or Sugarbush (SUCRAL). This plain is part of the action zone of the Lokkos Regional Office of Agricultural Development (ORMVAL). Outside the perimeters of these large companies, some scattered parcels are exploited by private individuals [3] (Figure 1).

From an industrial standpoint, several factories are in place and / or being installed to ensure the valorisation and conditioning of various agricultural productions, including citrus, sugarcane, vegetables, etc.

Faced with its installed activities, the groundwater level of the R'mel aquifer showed signs of very localized overexploitation, particularly in the northern areas which would increase the risk of seawater intrusion. In addition, impairment of the quality of the groundwater problems due to increased nitrates arises periodically.

The R'mel water table flows in the pliovillafranchian shell sandstone and quaternary dune sands. Both aquifer formations are generally separated by a villafranchian sandy loam or clay layer. The limits of this aquifer coincide with the limits of the plain of R'mel.

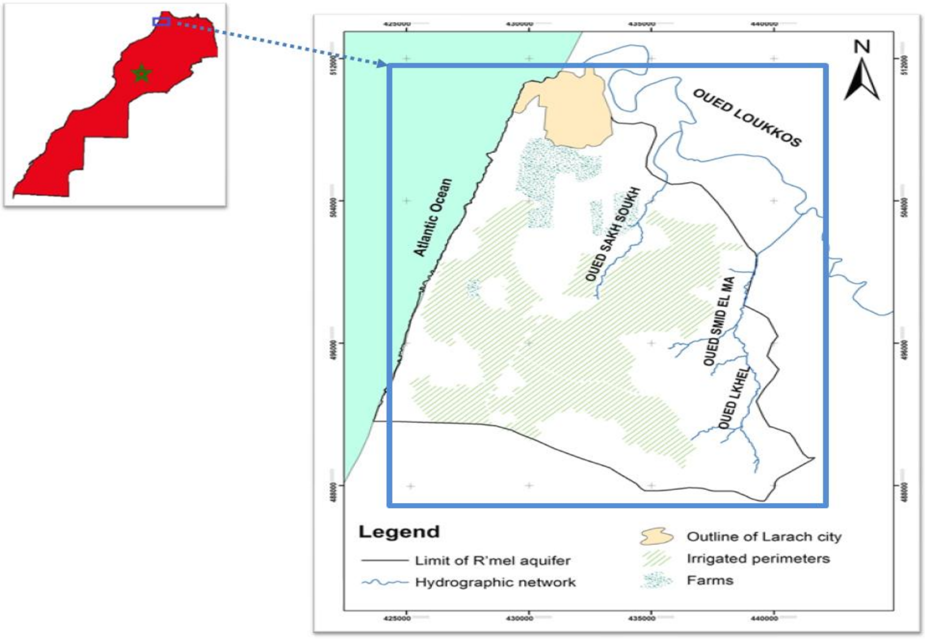

Figure 1: Geographic location of the study area

The bottom of the R'mel aquifer consists mainly of Miopliocen blue marl. The general flow is from South to North-East (Loukkos plain) and to the North-West (Atlantic Ocean). This direction is modified along the rivers (Sakh Sokh, Smid El Ma and El Kihel) and the talus where the aquifer is permanently drained, creating springs and merjas in some places. The depth of the water varies between 5 and 20 m [4].

2. Experimental details

2.1. *Principle of applying the GALDIT approach*

The GALDIT approach is a specific method developed by [2] to characterize the vulnerability of coastal aquifers, based on six parameters :

(G) - Groundwater Occurrence (Aquifer type). Vulnerability to seawater intrusion depends on the type of the aquifer that can be confined, leaky confined or unconfined. Under natural conditions, the unconfined aquifer is the most exposed to seawater intrusion due to the lack of an impermeable top compared to the confined or semi-confined aquifer. However, in the case of overexploitation, excessive pumping may create a depression cone and calls for sea water and thus generates the salt wedge.

(A) - Aquifer Hydraulic Conductivity. For the same operating conditions, the speed of advance of the salt front is closely related to the hydraulic conductivity.

(L) - Depth to groundwater Level above the sea (depth of the water to the zero sea level). This parameter determines the hydraulic pressure that can push the salt front.

(D) - Distance from the Shore (distance inland perpendicular from shoreline). The impact of seawater intrusion decreases by moving away from the coast.

(I) - Impact of existing status of seawater intrusion in the area. In this method, it is proposed to use the $Cl^- / (HCO_3^{-1} + CO_3^{2-})$ ratio as a measure of seawater intrusion in coastal aquifers. The chloride ion is dominant in seawater and slightly present in groundwater, and conversely for bicarbonates. The case where this Ratio is <1 indicates a very low seawater intrusion.

(T) - Thickness of the aquifer. The expansion of seawater intrusion increases with thickness of the aquifer.

This new approach is applied to various coastal aquifers on a national and international scale [5-11].

To develop the six GALDIT indexed maps and the final map of groundwater vulnerability to seawater intrusion, we followed the protocol of application of the PRK approach developed by [12], following the steps below :

(1)- Delimitation of the study area where combining operations will be performed.

(2)- Calculation of the partial indices relative to the six parameters of the acronym GALDIT at each pixel of the study area. In this step, an independent mapping must be carried out for each parameter before combining them.

The table 1 shows the different partial indices (I_I), represented in a more flexible way.

Table 1: Matrix of correspondence and digitization of partial indices (I_I)

Parameters	***Weight***	***Classes & Ranges***			
		Very Low	***Low***	***Medium***	***High***
		2.5	***5***	***7.5***	***10***
G	***1***	*Bounded Aquifer*	*Leaky confined*	*Unconfined*	*Confined*
A	***3***	*<5*	*5 - 10*	*10 - 40*	*>40*
L	***4***	*>2*	*1.5 - 2*	*1- 1.5*	*<1*
D	***4***	*>1000*	*1000 -750*	*750-500*	*<500*
I	***1***	*<1*	*1-1.5*	*1.5 - 2*	*>2*
T	***2***	*<5*	*5 - 7.5*	*7.5 - 10*	*>10*

Source : [2]

(3)- Automatic calculation of the GALDIT Index (Iv) by multiplicative combination of the six index maps at each pixel of the study area, following equation (1) : $Iv = \sum_{i=1}^{6}(Wi * Ni) / \sum_{i=1}^{6} Wi$ (1)

Where : Wi is the weight (1 à 4) and Ni is the rating (2.5 à 10) of the ithem parameter.

The final result is an interval between a lower bound < 5 and an upper bound, above 7.5. The selected subdivisions are : Class >7.5 ⇔ Very High Vulnerability, Class [5-7.5[⇔ Moderate Vulnerability & Class < 5 ⇔ Low Vulnerability [1-2]. Higher value of GALDIT index indicates high vulnerability to seawater intrusion.

(4)- Mapping the degree of vulnerability of groundwater zoning of areas of the same classes of variation.

By convention, we use a duplicate code range of colors (hot and cold) increasing on both sides of the yellow. Colors with warm tones ranging from orange to red, will be assigned to an index expressing a moderate to Very High vulnerability. Colors in cold tones, case of green, will be assigned to a low index, reflecting a low vulnerability. Empty classes with no values, will have a black tint.

Class of Very High Vulnerability ⇔ Red color, Class of Moderate Vulnerability ⇔ Orange color & Class of Low Vulnerability ⇔ Green color.

2.2. *Data used*

To develop the intrinsic vulnerability map of the R'mel aquifer to seawater intrusion, the data and documents used are :

Map of the spatial distribution of the parameter "G", elaborated according to the R'mel aquifer contour provided by the Agency of the Hydraulic Basin of the Loukkos (ABHL).

Map of the spatial distribution of the parameter "A", performed by interpolating on GIS the hydraulic conductivity values recorded on the boreholes drilled files archived at the ABHL and consultation of [4].

Map of the spatial distribution of the parameter "L", based on the interpolation of the piezometric data (April 2015) provided by the ABHL.

Map of the spatial distribution of parameter "D", developed by direct application on GIS.

Map of the spatial distribution of the parameter "I", developed by interpolation of the water quality data of the aquifer (April 2015) archived in the laboratory of the ABHL.

Map of the spatial distribution of the parameter "T", based on the observation of the asynchronous values of the aquifer thickness recorded on the boreholes drilled files implanted in the study area and archived at the ABHL, and consultation of [4].

2.3. Computer tools used

For the mapping and combination of the six parameters required for the GALDIT model, the GIS tool used is ArcGIS - Version 10.3 (developed by ESRI : Environmental Systems Research Institute).

3. Results and Discussion

The calculation of the ratings assigned to each parameter of the acronym GALDIT allowed to assess the spatial distribution of the degree of groundwater vulnerability to pollution (Figures 2 to 7). The final calculation of the GALDIT index was carried out automatically by the GIS used (Figure 8).

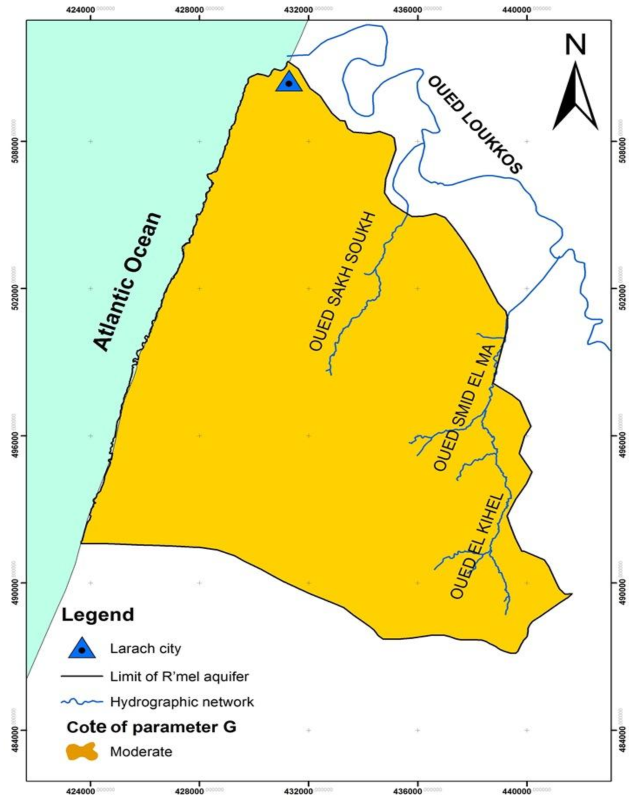

Figure 2: Individual vulnerability related to parameter "G"

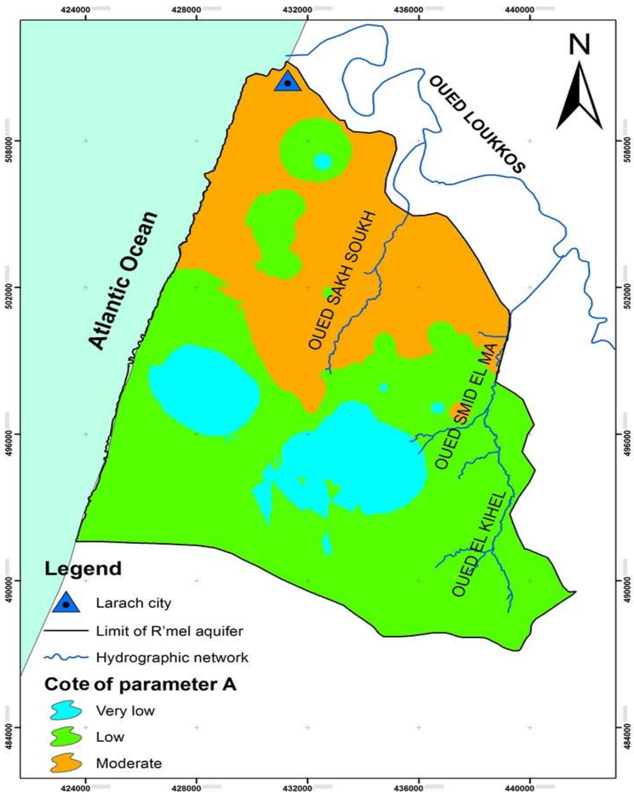

Figure 3: Individual vulnerability related to parameter "A"

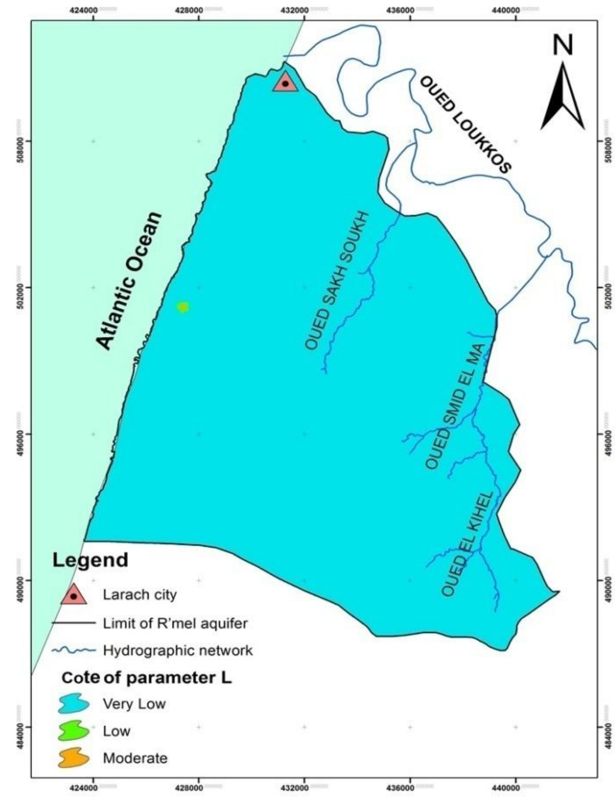

Figure 4: Individual vulnerability related to parameter "L"

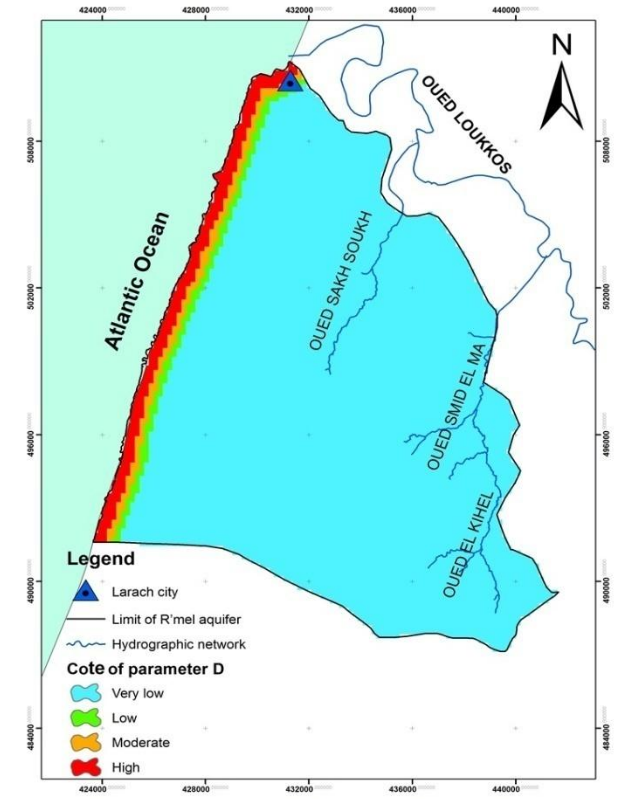

Figure 5: Individual vulnerability related to parameter "D"

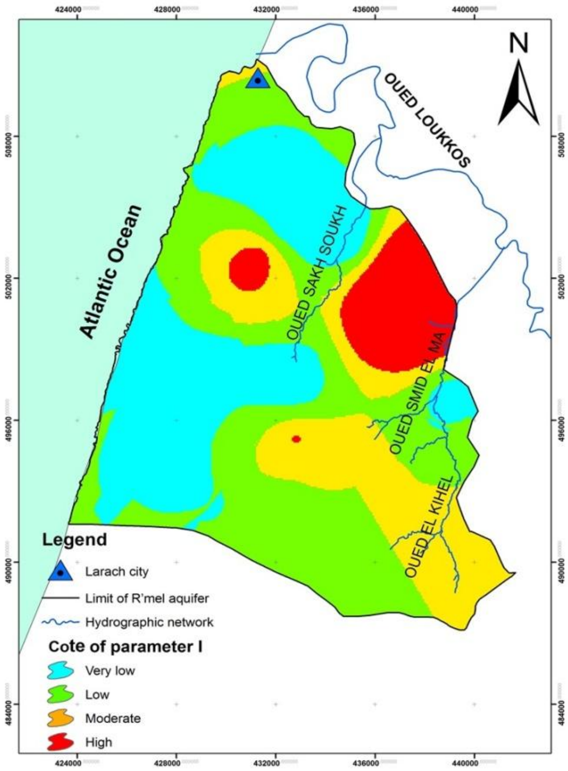

Figure 6: Individual vulnerability related to parameter "I"

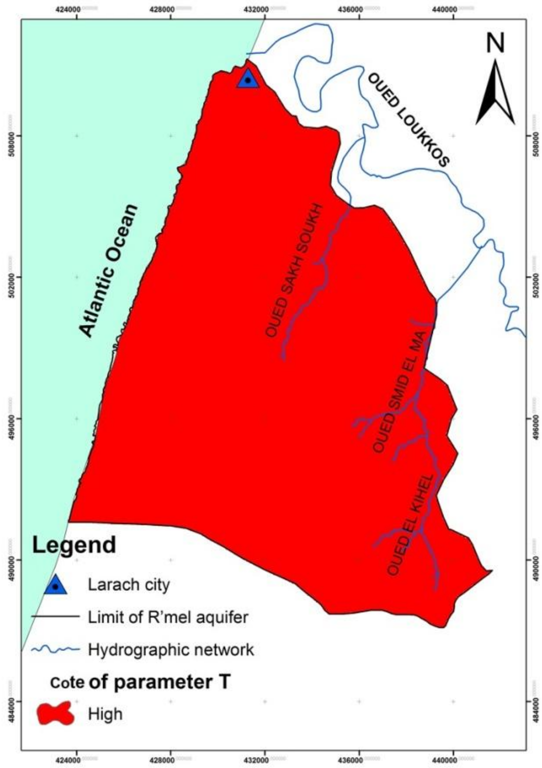

Figure 7: Individual vulnerability related to parameter "T"

The final result is a vulnerability map, which supports the six parameters of the acronym GALDIT. It reflects the vulnerability of the hydrogeological system to seawater intrusion by gathering the global index by classes (Figure 8).

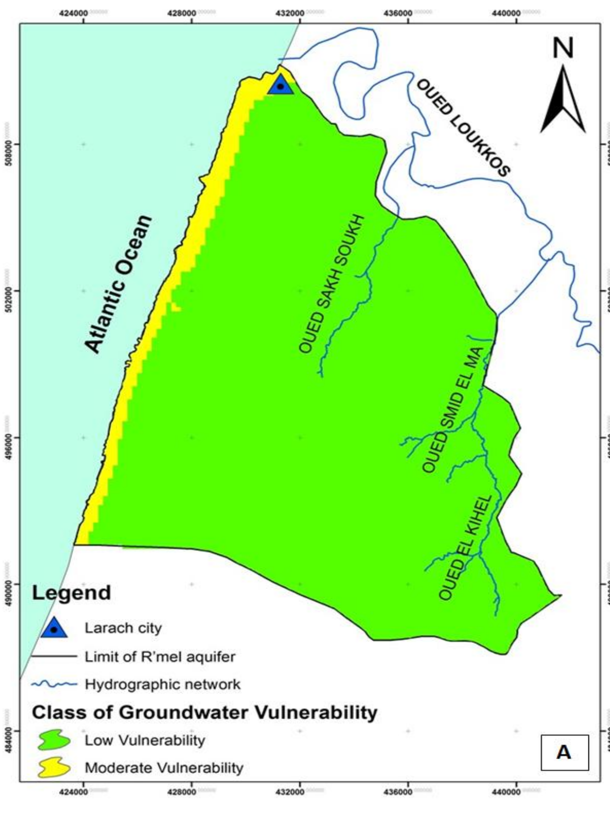

Figure 8: (A) Intrinsic vulnerability of R'mel groundwater against seawater intrusion - (B) Spatial distribution of vulnerability of R'mel groundwater against seawater intrusion

The global indices obtained by this combination vary between 3 and 7. They are distributed in two classes corresponding to the degrees of vulnerability fluctuating from "Low" to "Moderate". The dominant class is "Low vulnerability", covering up to 73% of the total area.

Conclusions

The application of GALDIT approach allowed us to assess the vulnerability of the coastal aquifer of R'mel against seawater intrusion. This derived map can be used as a tool for management of the coastal groundwater resources.

The confrontation of the 7 resulting index maps shows that the final cartographic document takes essentially the form of the index map relating to the criteria "D".

The parameter "D" contributes the most to the variability of the R'mel groundwater. The most static parameters are "G", "L" and "T". On the other hand, the tendency to exploit the groundwater of R'mel has favored the local increase in the chlorides / bicarbonates ratio, strong indicator of the seawater intrusion. This ratio is more important around some boreholes used for drinking water and along the shore of the the Atlantic Ocean.

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